

METHOD AND SYSTEM FOR SURFACE PRODUCTION OF
GAS FROM A SUBTERRANEAN ZONE

RELATED APPLICATIONS

This application is a continuation-in-part of pending patent application Serial No. 09/444,029 filed November 19, 1999 and entitled *Method and System for Accessing Subterranean Deposits from the Surface*, which is a continuation-in-part of U.S. Patent No. 6,280,000 filed November 20, 1998 and entitled *Method for Production of Gas from a Coal Seam*.

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TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to the recovery of subterranean resources, and more particularly to a method and system for surface production of gas from a subterranean zone.

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BACKGROUND OF THE INVENTION

Subterranean deposits of coal, whether of "hard" coal such as anthracite or "soft" coal such as lignite or bituminous coal, contain substantial quantities of entrained methane gas. Limited production and use of methane gas from coal deposits has occurred for many years. Substantial obstacles have frustrated more extensive development and use of methane gas deposits in coal seams.

10 One problem in producing methane gas from coal seams
is that while coal seams may extend over large areas, up
to several thousand acres, the coal seams are typically
fairly shallow in depth, varying from a few inches to
several meters and have a low permeability. Thus, while
15 the coal seams are often relatively near the surface,
vertical wells drilled into the coal deposits for
obtaining methane gas can only drain a fairly small
radius around the coal deposits. Further, coal deposits
are not amenable to pressure fracturing and other methods
20 often used for increasing methane gas production from
rock formations. As a result, once the gas easily
drained from a vertical well bore in a coal seam is
produced, further production is limited.

Another problem in producing methane gas from coal seams is subterranean water which must be drained from the coal seam in order to produce the methane. As water is removed from the coal seam, much of it is replaced with recharge water flowing from other virgin areas of the coal seam and/or adjacent formations. This recharge of the coal seam extends the time required to drain the coal seam and thus prolongs the production time for entrained methane gas. For example, in Appalachia, it may take four or five months of pumping water from a coal

seam before the recharge water head pressure has dropped to a point where gas can be produced. When the area of the coal seam being drained is near a mine or other subterranean structure that reduces recharge water by 5 itself draining water from the coal seam, methane gas may be produced from the coal seam after a shorter period of water removal.

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SUMMARY OF THE INVENTION

The present invention provides a method and system for surface production of gas from a subterranean zone that substantially eliminates or reduces the 5 disadvantages and problems associated with previous systems and methods. In a particular embodiment, water and gas are produced from a coal seam or other suitable subterranean zone through a horizontal drainage pattern having a plurality of cooperating bores that lower water 10 pressure throughout the coverage area of the pattern to allow accelerated release of gas in the zone and expedited production of the gas at the surface.

In accordance with one embodiment of the present invention, a method and system for subsurface production 15 of gas from a subterranean zone includes forming a drainage pattern in a subsurface zone. The drainage pattern includes a plurality of cooperating bores and has a coverage area extending between the cooperating bores. Water pressure is lowered throughout the coverage area of 20 the subsurface zone without significant subsurface drainage by producing water through the cooperating bores of the drainage pattern to the surface. In a particular embodiment, the water pressure may be substantially uniformly reduced across the coverage area and/or quickly 25 lowered. Gas is co-produced from the coverage area of the subsurface zone with at least some of the water.

Technical advantages of the present invention include providing accelerated gas production from subsurface coal, shale and other suitable formations. In 30 particular, entrained water pressure of a target formation is substantially uniformly reduced across a coverage area to initiate early gas release. Gas may be produced in two-phase flow with the entrained water. In

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addition, the released gas may lower the specific gravity and/or viscosity of the produced fluid thereby further accelerating production from the formation. Moreover, the released gas may act as a propellant for two-phase 5 flow production. In addition, the pressure reduction may affect a large rock volume causing a bulk coal or other formation matrix to shrink and further accelerate gas release. For a coal formation, the attendant increase in cleat width may increase formation permeability and may 10 thereby further expedite gas production from the formation.

Other technical advantages of the present invention include providing a substantially uniform pressure drop across a non-disjointed coverage area of the drainage 15 pattern. As a result, substantially all of the formation in the coverage area is exposed to a drainage point and continuity of the flow unit is enhanced. Thus, trapped zones of unrecovered gas are minimized.

Additional technical advantages of the present 20 invention include providing a drainage pattern with cooperating bores that effectively increase well-bore radius. In particular, a large surface area of lateral bores promotes high flow rates and minimizes skin damage affects. In addition, troughs of pressure reduction of 25 the lateral bores effects a greater area of the formation than a cone of pressure reduction of a vertical bore.

Still other technical advantages of the present invention include maintaining hydraulic seal integrity of a coal or other suitable formation during gas production. 30 A pinnate or other substantially uniform pattern allows gas production without hydraulic fracturing operations which may fracture seals between the coal and adjacent water bearing sands and cause significant water influx.

In addition, the cooperating bores capture at the tips recharge water caused by high permeability and/or active aquifers to provide a shield for the coverage area, trapped cell pressure reduction and continued depleted pressure between the cooperating bores.

Still another technical advantage of the present invention includes providing self-sustaining gas production in a coal, shale or other suitable seam. In particular, water volume is suitably drawn down in the reservoir within a few weeks of the start of water production to kick off the well. Thereafter, a chain reaction sustains gas production and lifts water with the gas.

Yet another technical advantage of the present invention includes providing enhanced and/or accelerated rate of returns for coal bed methane and other suitable gas production. In particular, accelerated production of gas allows drilling and operating expenses for gas production of a field to become self-sustaining within a year as opposed to a three to five year period for typical production operations. As a result, use of capital per field is reduced.

The above and elsewhere described technical advantages of the present invention may be provided and/or evidenced by some, all or none of the various embodiments of the present invention. In addition, other technical advantages of the present invention may be readily apparent to one skilled in the art from the following figures, descriptions and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and its advantages, reference is now made to the following description taken in conjunction with the 5 accompanying drawings, wherein like numerals represent like parts, in which:

FIGURE 1 is a cross-sectional diagram illustrating formation of a horizontal drainage pattern in a subterranean zone through an articulated surface well 10 intersecting a vertical cavity well in accordance with one embodiment of the present invention;

FIGURE 2 is a cross-sectional diagram illustrating formation of the horizontal drainage pattern in the subterranean zone through the articulated surface well 15 intersecting the vertical cavity well in accordance with another embodiment of the present invention;

FIGURE 3 is a cross-sectional diagram illustrating production of fluids from the horizontal draining pattern through the vertical well bore in accordance with one 20 embodiment of the present invention;

FIGURE 4 is a top plan diagram illustrating a pinnate drainage pattern for accessing products in the subterranean zone in accordance with one embodiment of the present invention;

25 FIGURE 5 is a top plan diagram illustrating a pinnate drainage pattern for accessing products in the subterranean zone in accordance with another embodiment of the present invention;

FIGURE 6 is a top plan diagram illustrating a 30 quadrilateral pinnate drainage pattern for accessing products in the subterranean zone in accordance with one embodiment of the present invention;

FIGURE 7 is a top plan diagram illustrating an alignment of pinnate drainage patterns in the subterranean zone in accordance with one embodiment of the present invention;

5 FIGURE 8 is a top plan diagram illustrating a pinnate drainage pattern for accessing products in the subterranean zone in accordance with another embodiment of the present invention;

10 FIGURE 9 is a top plan diagram illustrating a pinnate drainage pattern for accessing products in the subterranean zone in accordance with still another embodiment of the present invention;

15 FIGURE 10 is a top plan diagram illustrating a pinnate drainage pattern for accessing products in the subterranean zone in accordance with still another embodiment of the present invention;

20 FIGURE 11 is a top plan diagram illustrating a tripinnate drainage pattern for accessing products in the subterranean zone in accordance with one embodiment of the present invention;

25 FIGURE 12 is a top plan diagram illustrating an alignment of tripinnate drainage patterns in the subterranean zone in accordance with one embodiment of the present invention;

30 FIGURE 13 is a top plan diagram illustrating a pinnate drainage pattern for accessing products in the subterranean zone in accordance with still another embodiment of the present invention;

FIGURE 14 is a top plan diagram illustrating 35 pressure drop in the subterranean zone across a coverage area of the pinnate pattern of FIGURE 8 during production of gas and water in accordance with one embodiment of the present invention;

FIGURE 15 is a chart illustrating pressure drop in the subterranean zone across line 15-15 of FIGURE 14 in accordance with one embodiment of the present invention;

FIGURE 16 is a diagram illustrating the structure of 5 coal in the coal seam in accordance with one embodiment of the present invention;

FIGURE 17 is a flow diagram illustrating a method for surface production of gas from the coal seam in accordance with embodiment of the present invention; and

10 FIGURE 18 is a graph illustrating gas production curves for gas from the subterranean zone in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIGURE 1 illustrates a system 10 for enhanced access to a subterranean, or subsurface, zone from the surface in accordance with an embodiment of the present invention. In this embodiment, the subterranean zone is a coal seam. It will be understood that other suitable types of zones and/or other types of low pressure, ultra-low pressure, and low porosity subterranean formations can be similarly accessed using the present invention to remove and/or produce water, hydrocarbons such as methane gas and other products from the zone, to treat the zone, or to inject or introduce a gas, fluid or other substance into the zone.

Referring to FIGURE 1, the system 10 includes a well bore 12 extending from the surface 14 to a target coal seam 15. The well bore 12 intersects, penetrates and continues below the coal seam 15. The well bore 12 is lined with a suitable well casing 16 that terminates at or above the level of the coal seam 15. The well bore 12 is substantially vertical in that it allows a sucker rod, a Moineau or other suitable screw type and/or other suitable type of bore hole pump to lift fluids up the bore 12 to the surface 14. Thus, the well bore 12 may include suitable angles to accommodate surface 14 characteristics, geometric characteristics of the coal seam 15, characteristics of intermediate formations and/or may be slanted at a suitable angle.

The well bore 12 is logged either during or after drilling in order to closely approximate and/or locate the exact vertical depth of the coal seam 15. As a result, the coal seam 15 is not missed in subsequent drilling operations. In addition, techniques used to

locate the coal seam 15 while drilling need not be employed.

An enlarged cavity 20 is formed in the well bore 12 proximate the coal seam 15. As described in more detail 5 below, the enlarged cavity 20 provides a junction for intersection of the well bore 12 by an articulated well bore used to form a subterranean well bore pattern in the coal seam 15. The enlarged cavity 20 also provides a collection point for fluids drained from the coal seam 15 10 during production operations.

In one embodiment, the enlarged cavity 20 has a radius of approximately eight feet and a vertical dimension that equals or exceeds the vertical dimension of the coal seam 15. In another embodiment, the cavity 15 20 may have an enlarged substantially rectangular cross section perpendicular to an articulated well bore for intersection by the articulated well bore and a narrow depth through which the articulated well bore passes. The enlarged cavity 20 is formed using suitable underreaming techniques and equipment such as a dual blade 20 tool using centrifugal force, ratcheting or a piston for actuation, a pantograph and the like. A portion of the well bore 12 continues below the enlarged cavity 20 to form a sump 22 for the cavity 20.

An articulated well bore 30 extends from the surface 25 14 to the enlarged cavity 20 of the well bore 12. The articulated well bore 30 includes a portion 32, a portion 34, and a curved or radiused portion 36 interconnecting the portions 32 and 34. The portion 32 is substantially 30 vertical. As previously described, portion 32 may be formed at any suitable angle relative to the surface 14 to accommodate surface 14 geometric characteristics and attitudes and/or the geometric configuration or attitude

of the coal seam 15. The portion 34 is substantially horizontal in that it lies substantially in the plane of the coal seam 15. The portion 34 intersects the enlarged cavity 20 of the well bore 12. It should be understood 5 that portion 34 may be formed at any suitable angle relative to the surface 14 to accommodate the dip or other geometric characteristics of the coal seam 15.

In the embodiment illustrated in FIGURE 1, the articulated well bore 30 is offset a sufficient distance 10 from the well bore 12 at the surface 14 to permit the large radius curved section 36 and any desired portion 34 to be drilled before intersecting the enlarged cavity 20. To provide the curved portion 36 with a radius of 100-150 feet, the articulated well bore 30 is offset a distance 15 of about 300 feet from the well bore 12. This spacing minimizes the angle of the curved portion 36 to reduce friction in the articulated well bore 30 during drilling operations. As a result, reach of the drill string through the articulated well bore 30 is maximized. In 20 another embodiment, the articulated well bore 30 may be located within close proximity of the well bore 12 at the surface 14 to minimize the surface area for drilling and production operations.

The articulated well bore 30 is drilled using a 25 drill string 40 that includes a suitable down-hole motor and bit 42. A measurement while drilling (MWD) device 44 is included in the articulated drill string 40 for controlling the orientation and direction of the well bore drilled by the motor and bit 42. The portion 32 of 30 the articulated well bore 30 is lined with a suitable casing 38.

After the enlarged cavity 20 has been successfully intersected by the articulated well bore 30, drilling is

continued through the cavity 20 using the articulated drill string 40 and appropriate drilling apparatus to provide a subterranean well bore, or drainage pattern 50 in the coal seam 15. The well bore pattern 50 is substantially horizontal corresponding to the geometric characteristics of the coal seam 15. The well bore pattern 50 may include sloped, undulating, or other inclinations of the coal seam 15 or other subterranean zone. During formation of well bore pattern 50, gamma ray logging tools and conventional MWD devices may be employed to control and direct the orientation of the drill bit 42 to retain the well bore pattern 50 within the confines of the coal seam 15 and to provide substantially uniform coverage of a desired area within the coal seam 15.

During the process of drilling the well bore pattern 50, drilling fluid or "mud" is pumped down the drill string 40 and circulated out of the drill string 40 in the vicinity of the bit 42, where it is used to scour the formation and to remove formation cuttings. The cuttings are then entrained in the drilling fluid which circulates up through the annulus between the drill string 40 and the walls of well bore 30 until it reaches the surface 14, where the cuttings are removed from the drilling fluid and the fluid is then recirculated. This conventional drilling operation produces a standard column of drilling fluid having a vertical height equal to the depth of the well bore 30 and produces a hydrostatic pressure on the well bore 30 corresponding to the well bore 30 depth. Because coal seams 15 tend to be porous and fractured, they may be unable to sustain such hydrostatic pressure, even if formation water is also present in the coal seam 15. Accordingly, if the full

hydrostatic pressure is allowed to act on the coal seam 15, the result may be loss of drilling fluid and entrained cuttings into the formation. Such a circumstance is referred to as an "over-balanced" 5 drilling operation in which the hydrostatic fluid pressure in the well bore 30 exceeds the ability of the formation to withstand the pressure. Loss of drilling fluids and cuttings into the formation not only is expensive in terms of the lost drilling fluids, which 10 must be made up, but it also tends to plug the pores in the coal seam 15, which are needed to drain the coal seam 15 of gas and water.

To prevent over-balance drilling conditions during formation of the well bore pattern 50, air compressors 60 15 may be provided to circulate compressed air down the well bore 12 and back up through the articulated well bore 30. The circulated air will admix with the drilling fluids in the annulus around the drill string 40 and create bubbles throughout the column of drilling fluid. This has the 20 effect of lightening the hydrostatic pressure of the drilling fluid and reducing the down-hole pressure sufficiently that drilling conditions do not become over-balanced. Aeration of the drilling fluid reduces down-hole pressure to approximately 150-200 pounds per square 25 inch (psi). Accordingly, low pressure coal seams and other subterranean resources can be drilled without substantial loss of drilling fluid and contamination of the resource by the drilling fluid.

Foam, which may be compressed air mixed with water, 30 may also be circulated down through the drill string 40 along with the drilling mud in order to aerate the drilling fluid in the annulus as the articulated well bore 30 is being drilled and, if desired, as the well

bore pattern 50 is being drilled. Drilling of the well bore pattern 50 with the use of an air hammer bit or an air-powered down-hole motor will also supply compressed air or foam to the drilling fluid. In this case, the 5 compressed air or foam which is used to power the down-hole motor and bit 42 exits the articulated drill string 40 in the vicinity of the drill bit 42. However, the larger volume of air which can be circulated down the well bore 12 permits greater aeration of the drilling 10 fluid than generally is possible by air supplied through the drill string 40.

FIGURE 2 is a diagram illustrating system 10 for enhanced access to a subterranean zone from the surface in accordance with another embodiment of the present 15 invention. In this embodiment, the well bore 12, enlarged cavity 20 and articulated well bore 30 are positioned and formed as previously described in connection with FIGURE 1. Referring to FIGURE 2, after intersection of the enlarged cavity 20 by the articulated 20 well bore 30, a Moineau or other suitable pump 52 is installed in the enlarged cavity 20 to pump drilling fluid and cuttings to the surface 14 through the well bore 12. This eliminates the friction of air and fluid returning up the articulated well bore 30 and reduces 25 down-hole pressure to nearly zero. Accordingly, coal seams and other subterranean resources having ultra low pressures below 150 psi can be accessed from the surface 14. Additionally, the risk of combining air and methane in the well is eliminated.

30 FIGURE 3 is a diagram illustrating system 10 during production operations. In this embodiment, after the well bores 12 and 30, and well bore pattern 50 have been drilled, the drill string 40 is removed from the

articulated well bore 30 and the articulated well bore 30 is capped. A pumping unit 80 is disposed in the well bore 12 in the enlarged cavity 20. The enlarged cavity 20 provides a reservoir for accumulated fluids allowing 5 intermittent pumping without adverse effects of a hydrostatic head caused by accumulated fluids in the well bore 12. As a result, a large volume of fluids may be collected in the cavity without any pressure or any substantial pressure being exerted on the formation from 10 the collected fluids. Thus, even during periods of non-pumping, water and/or gas may continue to flow from the well bore pattern 50 and accumulate in the cavity 20.

The pumping unit 80 includes an inlet 82 in the cavity 20 and may comprise a tubing string 82 with sucker 15 rods 84 extending down through the well bore 12 of the tubing string 82. The inlet 82 should be positioned to avoid gas lock and to avoid debris that collects in a sump 22 of the cavity 20. The sucker rods 84 are reciprocated by a suitable surface mounted apparatus, 20 such as a powered walking beam 86 to operate the pumping unit 80. In another embodiment, the pumping unit 80 may comprise a Moineau or other suitable pump operable to lift fluids vertically or substantially vertically. The pumping unit 80 is used to remove water and entrained 25 coal fines from the coal seam 15 via the well bore pattern 50. Once the water is removed to the surface 14, it may be treated for separation of methane which may be dissolved in the water and for removal of entrained fines. After sufficient water has been removed from the 30 coal seam 15, coal seam gas may be allowed to flow from the coal seam 15 to the surface 14 through the annulus of the well bore 12 around the tubing string 82 and removed via piping attached to a wellhead apparatus. At the

surface 14, the methane is treated, compressed and pumped through a pipeline for use as a fuel in a conventional manner. The pumping unit 80 may be operated continuously or as needed to remove water drained from the coal seam 5 15 into the enlarged cavity 20.

As described in more detail below, water pressure must typically be reduced below the reservoir pressure of an area of the coal seam 15 before methane gas will diffuse from the coal in that area. For shallow coal 10 beds at or around 1000 feet, the reservoir pressure is typically about 300 psi. Sufficient reduction in the water pressure for gas production may take weeks and/or months depending on configuration of the well bore pattern 50, water recharge in the coal seam 15, cavity 15 pumping rates and/or any subsurface drainage through mines and other man made or natural structures that drain water from the coal seam 15 without surface lift.

In accordance with one aspect of the present invention, water pressured in a coverage area of the well 20 bore pattern 50 is reduced without significant subsurface drainage by producing water through cooperating bores of the well bore pattern 50 to the surface. The cooperating bores may provide a substantially uniform pressure drop across the coverage area. Subsurface drainage is not 25 significant in virgin reservoir conditions of the coverage area and/or when the coverage area of the drainage pattern is spaced 3,000 or more feet from a mine or other non surface-lift drainage structure such that any interaction between the pattern 50 and the structure 30 is minimal or non existent and/or the coverage area is subject to a net influx of water from the surrounding formation during water and/or gas production. In other embodiments, the well bore pattern 50 may be spaced 4000,

5000, 6000 or more feet away from a subsurface non lift drainage structure to be without significant subsurface drainage and/or to be in virgin reservoir conditions.

In a particular embodiment, the well bore pattern 50 5 may be configured to result in a net drainage in the coverage area (overall water volume pumped to the surface 14 less influx water volume from the surrounding areas and/or formations) of one tenth of the initial water volume in the first 17 to 25 days of water production in 10 order to "kick off" or induce early and/or self sustaining gas release. In one embodiment, early gas release may be through a chain reaction through an ever reducing reservoir pressure. Self sustaining gas release provides gas lift to remove water without further 15 pumping. Such gas may be produced in two-phase flow with the water. In addition, the released gas may lower the specific gravity and/or viscosity of the produced fluid thereby further accelerating gas production from the formation. Moreover, the released gas may act as a 20 propellant for further two-phase flow and/or production. The pressure reduction may affect a large rock volume causing a bulk coal or other formation matrix shrinkage and further accelerating gas release. For the coal seam 15, an attended increase in cleat width may increase 25 formation permeability and thereby further expedite gas production from the formation. It will be understood that early gas release may be initiated with all, some or none of the further enhancements to production.

FIGURES 4-13 illustrate well bore or drainage 30 patterns 50 for accessing the coal seam 15 or other subterranean zone in accordance with various embodiments of the present invention. In these embodiments, the well bore patterns 50 comprise one or more pinnate well bore

patterns that each have a central diagonal or other main bore with generally symmetrically arranged and appropriately spaced laterals extending from each side of the diagonal. As used herein, the term each means 5 everyone of at least a subset of the identified items.

The pinnate patterns approximate the pattern of veins in a leaf or the design of a feather in that it has similar, substantially parallel, auxiliary drainage bores arranged in substantially equal and parallel spacing on 10 opposite sides of an axis. The pinnate drainage patterns with their central bore and generally symmetrically arranged and appropriately spaced auxiliary drainage bores on each side provide a substantially uniform pattern for draining fluids from a coal seam 15 or other 15 subterranean formation.

As described in more detail below, the pinnate patterns may provide substantially uniform coverage of a non-disjointed area having a high area to perimeter ratio. Coverage is substantially uniform when the 20 pressure differential across the coverage area is less than or equal to twenty psi for a mature well, for example, with declining gas production or when less than ten percent of the area bounded by the pattern comprises trapped cells. In a particular embodiment, the pressure 25 differential may be less than ten psi. The coverage area may be a square, other quadrilateral, or other polygon, circular, oval or other ellipsoid or grid area and may be nested with other patterns of the same or similar type. It will be understood that other suitable well bore 30 patterns 50 may be used in accordance with the present invention.

The pinnate and other suitable well bore patterns 50 drilled from the surface 14 provide surface access to

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subterranean formations. The well bore pattern 50 may be used to uniformly remove and/or insert fluids or otherwise manipulate a subterranean zone. In non-coal applications, the well bore pattern 50 may be used 5 initiating in-situ burns, "huff-puff" steam operations for heavy crude oil, and the removal of hydrocarbons from low porosity reservoirs. The well bore pattern 50 may also be used to uniformly inject or introduce a gas, fluid or other substance into a subterranean zone.

10 FIGURE 4 illustrates a pinnate well bore pattern 100 in accordance with one embodiment of the present invention. In this embodiment, the pinnate well bore pattern 100 provides access to a substantially square coverage area 102 of the subterranean zone. A number of 15 the pinnate well bore patterns 100 may be used together to provide uniform access to a large subterranean region.

Referring to FIGURE 4, the enlarged cavity 20 defines a first corner of the area 102. The pinnate pattern 100 includes a main well bore 104 extending 20 diagonally across the coverage area 102 to a distant corner 106 of the area 102. Preferably, the well bores 12 and 30 are positioned over the area 102 such that the main well bore 104 is drilled up the slope of the coal seam 15. This may facilitate collection of water, gas, 25 and other fluids from the area 102. The well bore 104 is drilled using the drill string 40 and extends from the enlarged cavity 20 in alignment with the articulated well bore 30.

A plurality of lateral well bores 110 extend from 30 opposites sides of well bore 104 to a periphery 112 of the area 102. The lateral bores 110 may mirror each other on opposite sides of the well bore 104 or may be offset from each other along the well bore 104. Each of

the lateral bores 110 includes a radius curving portion 114 extending from the well bore 104 and an elongated portion 116 formed after the curved portion 114 has reached a desired orientation. For uniform coverage of 5 the square area 102, pairs of lateral bores 110 may be substantially evenly spaced on each side of the well bore 104 and extend from the well bore 104 at an angle of approximately 45 degrees. The lateral bores 110 shorten 10 in length based on progression away from the enlarged cavity 20.

The pinnate well bore pattern 100 using a single well bore 104 and five pairs of lateral bores 110 may drain a coal seam area of approximately 150 acres in size. For this and other pinnate patterns, where a 15 smaller area is to be drained, or where the coal seam 15 has a different shape, such as a long, narrow shape, other shapes due to surface or subterranean topography, alternate pinnate well bore patterns may be employed by varying the angle of the lateral bores 110 to the well 20 bore 104 and the orientation of the lateral bores 110. Alternatively, lateral bores 110 can be drilled from only one side of the well bore 104 to form a one-half pinnate pattern.

As previously described, the well bore 104 and the 25 lateral bores 110 of pattern 100 as well as bores of other patterns are formed by drilling through the enlarged cavity 20 using the drill string 40 and an appropriate drilling apparatus. During this operation, gamma ray logging tools and conventional MWD technologies 30 may be employed to control the direction and orientation of the drill bit 42 so as to retain the well bore pattern within the confines of the coal seam 15 and to maintain

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proper spacing and orientation of the well bores 104 and 110.

In a particular embodiment, the well bore 104 and that of other patters are drilled with an incline at each 5 of a plurality of lateral kick-off points 108. After the well bore 104 is complete, the articulated drill string 40 is backed up to each successive lateral point 108 from which a lateral bore 110 is drilled on each side of the well bore 104. It will be understood that the pinnate 10 drainage pattern 100 may be otherwise suitably formed.

FIGURE 5 illustrates a pinnate well bore pattern 120 in accordance with another embodiment of the present invention. In this embodiment, the pinnate well bore pattern 120 drains a substantially rectangular area 122 15 of the coal seam 15. The pinnate well bore pattern 120 includes a main well bore 124 and a plurality of lateral bores 126 that are formed as described in connection with well bores 104 and 110 of FIGURE 4. For the substantially rectangular area 122, however, the lateral 20 well bores 126 on a first side of the well bore 124 include a shallow angle while the lateral bores 126 on the opposite side of the well bore 124 include a steeper angle to together provide uniform coverage of the area 122.

FIGURE 6 illustrates a quadrilateral pinnate well 25 bore pattern 140 in accordance with one embodiment of the present invention. The quadrilateral well bore pattern 140 includes four discrete pinnate well bore patterns 100 each used to access a quadrant of a region 142 covered by 30 the pinnate well bore pattern 140.

Each of the pinnate well bore patterns 100 includes a well bore 104 and a plurality of lateral well bores 110 extending from the well bore 104. In the quadrilateral

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embodiment, each of the well bores 104 and 110 is drilled from a common articulated well bore 30 through a cavity 20. This allows tighter spacing of the surface production equipment, wider coverage of a well bore pattern, and reduces drilling equipment and operations.

FIGURE 7 illustrates the alignment of pinnate well bore patterns 100 with planned subterranean structures of a coal seam 15 for degasifying and preparing the coal seam 15 for mining operations in accordance with one embodiment of the present invention. In this embodiment, the coal seam 15 will be mined using a longwall process. It will be understood that the present invention can be used to degasify coal seams for other types of mining operations.

15 Referring to FIGURE 7, planned coal panels 150 extend longitudinally from a longwall 152. In accordance with longwall mining practices, each panel 150 will be subsequently mined from a distant end toward the longwall 152 and the mine roof allowed to cave and fracture into 20 the opening behind the mining process. Prior to mining, the pinnate well bore patterns 100 are drilled into the panels 150 from the surface to degasify the panels 150 well ahead of mining operations. Each of the pinnate well bore patterns 100 is aligned with the planned 25 longwall 152 and panel 150 grid and covers portions of one or more panels 150. In this way, a region of a planned mine can be degasified from the surface based on subterranean structures and constraints, allowing a 30 subsurface formation to be degasified and mined within a short period of time.

FIGURE 8 illustrates a pinnate well bore pattern 200 in accordance with another embodiment of the present invention. In this embodiment, the pinnate well bore

pattern 200 provides access to a substantially square area 202 of a subterranean zone. As with the other pinnate patterns, a number of the pinnate patterns 200 may be used together in dual, triple, and quad pinnate 5 structures to provide uniform access to a large subterranean region.

Referring to FIGURE 8, the enlarged cavity 20 defines a first corner of the area 202, over which a pinnate well bore pattern 200 extends. The enlarged 10 cavity 20 defines a first corner of the area 202. The pinnate pattern 200 includes a main well bore 204 extending diagonally across the area 202 to a distant corner 206 of the area 202. Preferably, the main well bore 204 is drilled up the slope of the coal seam 15. 15 This may facilitate collection of water, gas, and other fluids from the area 202. The main well bore 204 is drilled using the drill string 40 and extends from the enlarged cavity 20 in alignment with the articulated well bore 30.

20 A plurality of lateral well bores 210 extend from the opposites sides of well bore 204 to a periphery 212 of the area 202. The lateral bores 210 may mirror each other on opposite sides of the well bore 204 or may be offset from each other along the well bore 204. Each of 25 the lateral well bores 210 includes a first radius curving portion 214 extending from the well bore 204, and an elongated portion 218. The first set of lateral well bores 210 located proximate to the cavity 20 may also include a second radius curving portion 216 formed after 30 the first curved portion 214 has reached a desired orientation. In this set, the elongated portion 218 is formed after the second curved portion 216 has reached a desired orientation. Thus, the first set of lateral well

bores 210 kicks or turns back towards the enlarged cavity 20 before extending outward through the formation, thereby extending the coverage area back towards the cavity 20 to provide enhanced uniform coverage of the 5 area 202. For uniform coverage of the square area 202, pairs of lateral well bores 210 may be substantially evenly spaced on each side of the well bore 204 and extend from the well bore 204 at an angle of approximately 45 degrees. The lateral well bores 210 10 shorten in length based on progression away from the enlarged cavity 20. Stated another way, the lateral well bores 210 lengthen based on proximity to the cavity 20 in order to provide an enlarged and uniform coverage area. Thus, the length from a tip of each lateral to the cavity 15 is substantially equal and at or close to the maximum reach of the drill string through the articulated well 30.

FIGURE 9 illustrates a pinnate well bore pattern 300 in accordance with another embodiment of the present 20 invention. In this embodiment, the pinnate well bore pattern 300 provides access to a substantially square area 302 of a subterranean zone. A number of the pinnate patterns 300 may be used together to provide uniform access to a large subterranean region.

25 Referring to FIGURE 9, the enlarged cavity 20 defines a first corner of the area 302. The pinnate well bore pattern 300 includes a main well bore 304 extending diagonally across the area 302 to a distant corner 306 of the area 302. In one embodiment, the well bore 304 is 30 drilled up the slope of the coal seam 15. This may facilitate collection of water, gas, and other fluids from the area 302. The well bore 304 is drilled using

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the drill string 40 and extends from the enlarged cavity 20 in alignment with the articulated well bore 30.

A set of lateral well bores 310 extend from opposite sides of well bore 304 to a periphery 312 of the area 5 302. The lateral well bores 310 may mirror each other on opposite sides of the well bore 304 or may be offset from each other along the well bore 304. Each of the lateral well bores 310 includes a radius curving portion 314 extending from the well bore 304 and an elongated portion 10 316 formed after the curved portion 314 has reached a desired orientation. For uniform coverage of the square area 302, pairs of lateral well bores 310 may be substantially evenly spaced on each side of the well bore 304 and extend from the well bore 304 at an angle of 15 approximately 45 degrees. However, the lateral well bores 310 may be formed at other suitable angular orientations relative to well bore 304.

The lateral well bores 310 shorten in length based on progression away from the enlarged diameter cavity 20. Thus, as illustrated in FIGURE 9, a distance to the periphery 312 for the pattern 300 as well as for other pinnate patterns from the cavity 20 or well bore 30 measured along the lateral well bores 310 is substantially equal for each lateral well bore 310, thereby enhancing coverage by drilling substantially to a maximum distance by each lateral.

In the embodiment illustrated in FIGURE 9, well bore pattern 300 also includes a set of secondary lateral well bores 320 extending from lateral well bores 310. The 30 secondary lateral well bores 320 may mirror each other on opposite sides of the lateral well bore 310 or may be offset from each other along the lateral well bore 310. Each of the secondary lateral well bores 320 includes a

radius curving portion 322 extending from the lateral well bore 310 and an elongated portion 324 formed after the curved portion 322 has reached a desired orientation. For uniform coverage of the area 302, pairs of secondary lateral well bores 320 may be disposed substantially equally spaced on each side of the lateral well bore 310. Additionally, secondary lateral well bores 320 extending from one lateral well bore 310 may be disposed to extend between secondary lateral well bores 320 extending from 5 an adjacent lateral well bore 310 to provide uniform coverage of the area 302. However, the quantity, spacing, and angular orientation of secondary lateral well bores 320 may be varied to accommodate a variety of resource areas, sizes and drainage requirements. It will 10 be understood that secondary lateral well bores 320 may be used in connection with other main laterals of other 15 suitable pinnate patterns.

FIGURE 10 illustrates a well bore pattern 400 in accordance with still another embodiment of the present 20 invention. In this embodiment, the well bore pattern 400 provides access to a substantially diamond or parallelogram-shaped area 402 of a subterranean resource. A number of the well bore patterns 400 may be used together to provide uniform access to a large 25 subterranean region.

Referring to FIGURE 10 the articulated well bore 30 defines a first corner of the area 402. The well bore pattern 400 includes a main well bore 404 extending diagonally across the area 402 to a distant corner 406 of 30 the area 402. For drainage applications, the well bores 12 and 30 may be positioned over the area 402 such that the well bore 404 is drilled up the slope of the coal seam 15. This may facilitate collection of water, gas,

and other fluids from the area 402. The well bore 404 is drilled using the drill string 40 and extends from the enlarged cavity 20 in alignment with the articulated well bore 30.

5 A plurality of lateral well bores 410 extend from the opposite sides of well bore 404 to a periphery 412 of the area 402. The lateral well bores 410 may mirror each other on opposite sides of the well bore 404 or may be offset from each other along the well bore 404. Each
10 of the lateral well bores 410 includes a radius curving portion 414 extending from the well bore 404 and an elongated portion 416 formed after the curved portion 414 has reached a desired orientation. For uniform coverage of the area 402, pairs of lateral well bores 410 may be
15 substantially equally spaced on each side of the well bore 404 and extend from the well bore 404 at an angle of approximately 60 degrees. The lateral well bores 410 shorten in length based on progression away from the enlarged diameter cavity 20. As with the other pinnate
20 patterns, the quantity and spacing of lateral well bores 410 may be varied to accommodate a variety of resource areas, sizes and well bore requirements. For example, lateral well bores 410 may be drilled from a single side of the well bore 404 to form a one-half pinnate pattern.

25 FIGURE 11 illustrates a tripinnate well bore pattern
440 in accordance with one embodiment of the present
invention. The tripinnate well bore pattern 440 includes
three discrete well bore patterns 400 each draining a
portion of a region 442 covered by the well bore pattern
30 440. Each of the well bore patterns 400 includes a well
bore 404 and a set of lateral well bores 410 extending
from the well bore 404. In the tri-pinnate pattern
embodiment illustrated in FIGURE 11, each of the well

bores 404 and 410 are drilled from a common articulated well bore 30 and fluid and/or gas may be removed from or introduced into the subterranean zone through a cavity 20 in communication with each well bore 404. This allows 5 tighter spacing of the surface production equipment, wider coverage of a well bore pattern and reduces drilling equipment and operations.

Each well bore 404 is formed at a location relative to other well bores 404 to accommodate access to a 10 particular subterranean region. For example, well bores 404 may be formed having a spacing or a distance between adjacent well bores 404 to accommodate access to a subterranean region such that only three well bores 404 are required. Thus, the spacing between adjacent well 15 bores 404 may be varied to accommodate varied concentrations of resources of a subterranean zone. Therefore, the spacing between adjacent well bores 404 may be substantially equal or may vary to accommodate the unique characteristics of a particular subterranean 20 resource. For example, in the embodiment illustrated in FIGURE 11, the spacing between each well bore 404 is substantially equal at an angle of approximately 120 degrees from each other, thereby resulting in each well bore pattern 400 extending in a direction approximately 25 120 degrees from an adjacent well bore pattern 400. However, other suitable well bore spacing angles, patterns or orientations may be used to accommodate the characteristics of a particular subterranean resource. Thus, as 30 illustrated in FIGURE 11, each well bore 404 and corresponding well bore pattern 400 extends outwardly from well bore 444 in a different direction, thereby forming a substantially symmetrical pattern. As will be illustrated in greater detail below, the symmetrically

formed well bore patterns may be positioned or nested adjacent each other to provide substantially uniform access to a subterranean zone.

In the embodiment illustrated in FIGURE 11, each 5 well bore pattern 400 also includes a set of lateral well bores 448 extending from lateral well bores 410. The lateral well bores 448 may mirror each other on opposite sides of the lateral well bore 410 or may be offset from each other along the lateral well bore 410. Each of the 10 lateral well bores 448 includes a radius curving portion 460 extending from the lateral well bore 410 and an elongated portion 462 formed after the curved portion 460 has reached a desired orientation. For uniform coverage of the region 442, pairs of lateral well bores 448 may be 15 disposed substantially equally spaced on each side of the lateral well bore 410. Additionally, lateral well bores 448 extending from one lateral well bore 410 may be disposed to extend between or proximate lateral well bores 448 extending from an adjacent lateral well bore 20 410 to provide uniform coverage of the region 442. However, the quantity, spacing, and angular orientation of lateral well bores 448 may be varied to accommodate a variety of resource areas, sizes and well bore requirements.

25 As described above in connection with FIGURE 10, each well bore pattern 400 generally provides access to a quadrilaterally shaped area or region 402. In FIGURE 10, the region 402 is substantially in the form of a diamond or parallelogram. As illustrated in FIGURE 11, the well 30 bore patterns 400 may be arranged such that sides 449 of each quadrilaterally shaped region 448 are disposed substantially in common with each other to provide uniform coverage of the region 442.

FIGURE 12 illustrates an alignment or nested arrangement of well bore patterns within a subterranean zone in accordance with an embodiment of the present invention. In this embodiment, three discreet well bore 5 patterns 400 are used to form a series of generally hexagonally configured well bore patterns 450, for example, similar to the well bore pattern 440 illustrated in FIGURE 11. Thus, the well bore pattern 450 comprises a set of well bore sub-patterns, such as well bore 10 patterns 400, to obtain a desired geometrical configuration or access shape. The well bore patterns 450 may be located relative to each other such that the well bore patterns 450 are nested in a generally honeycomb-shaped arrangement, thereby maximizing the area of access 15 to a subterranean resource using fewer well bore patterns 450. Prior to mining of the subterranean resource, the well bore patterns 450 may be drilled from the surface to degasify the subterranean resource well ahead of mining operations.

20 The quantity of discreet well bore patterns 400 may also be varied to produce other geometrically-configured well bore patterns such that the resulting well bore patterns may be nested to provide uniform coverage of a subterranean resource. For example, in FIGURES 11-12, 25 three discreet well bore patterns 400 are illustrated in communication with a central well bore 404, thereby forming a six-sided or hexagonally configured well bore pattern 440 and 450. However, greater or fewer than three discreet well bore patterns 400 may also be used in 30 communication with a central well bore 404 such that a plurality of the resulting multi-sided well bore patterns may be nested together to provide uniform coverage of a

subterranean resource and/or accommodate the geometric characteristics of a particular subterranean resource.

FIGURE 13 illustrates a well bore pattern 500 in accordance with an embodiment of the present invention.

5 In this embodiment, well bore pattern 500 comprises two discreet well bore patterns 502 each providing access to a portion of a region 504 covered by the well bore pattern 500. Each of the well bore patterns 502 includes a well bore 506 and a set of lateral well bores 508 10 extending from the well bore 506. In the embodiment illustrated in FIGURE 13, each of the well bores 506 and 508 are drilled from a common articulated well bore 30 and fluid and/or gas may be removed from or introduced into the subterranean zone through the cavity 20 of well 15 bore 12 in communication with each well bore 506. In this embodiment, the well bores 20 and 30 are illustrated offset from each other; however, it should be understood that well bore pattern 500 as well as other suitable pinnate patterns may also be formed using a common 20 surface well bore configuration with the wells slanting or otherwise separating beneath the surface. This may allow tighter spacing of the surface production equipment, wider coverage of a well bore pattern and reduce drilling equipment and operations.

25 Referring to FIGURE 13, the well bores 506 are disposed substantially opposite each other at an angle of approximately 180 degrees, thereby resulting in each well bore pattern 502 extending in an opposite direction. However, other suitable well bore spacing angles, 30 patterns or orientations may be used to accommodate the characteristics of a particular subterranean resource. In the embodiment illustrated in FIGURE 13, each well bore pattern 502 includes lateral well bores 508

extending from well bores 506. The lateral well bores 508 may mirror each other on opposite sides of the well bores 506 or may be offset from each other along the well bores 506. Each of the lateral well bores 508 includes a 5 radius curving portion 518 extending from the well bore 506 and an elongated portion 520 formed after the curved portion 518 has reached a desired orientation. For uniform coverage of the region 504, pairs of lateral well bores 508 may be disposed substantially equally spaced on 10 each side of the well bore 506. However, the quantity, spacing, and angular orientation of lateral well bores 508 may be varied to accommodate a variety of resource areas, sizes and well bore requirements. As described above, the lateral well bores 508 may be formed such that 15 the length of each lateral well bore 508 decreases as the distance between each respective lateral well bore 508 and the well bores 20 or 30 increases. Accordingly, the distance from the well bores 20 or 30 to a periphery of the region 504 along each lateral well bore 508 is 20 substantially equal, thereby providing ease of well bore formation.

In this embodiment, each well bore pattern 502 generally provides access to a triangular shaped area or region 522. The triangular shaped regions 522 are formed 25 by disposing the lateral well bores 508 substantially orthogonal to the well bores 506. The triangular shaped regions 522 are disposed adjacent each other such that each region 522 has a side 524 substantially in common with each other. The combination of regions 522 thereby 30 forms a substantially quadrilateral shaped region 504. As described above, multiple well bore patterns 500 may be nested together to provide substantially uniform access to subterranean zones.

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FIGURES 14-15 illustrate pressure drop across a coverage area of the well bore pattern 50 in accordance with one embodiment of the present invention. In this embodiment, the well bore pattern 50 is the pinnate pattern 200 described in connection with FIGURE 8. It will be understood that the other pinnate patterns generate a similar pressure drop across the coverage area.

Referring to FIGURE 14, the pinnate pattern 200 includes the main bore 204 and a plurality of equally spaced laterals 210. In a particular embodiment, the pinnate pattern 200 may cover an area of 250 acres, have a substantially equal width to length ratio and have the laterals 210 each spaced approximately 800 feet apart. In this embodiment, a substantial portion of the coverage area 202 may be within 400 feet from the main and/or lateral bores 204 and 210 with over 50 percent of the coverage area 202 being more than 150 to 200 feet away from the bores. The pattern 200, in conjunction with a pump, may be operable to remove 500 barrels per day of water, of which about ninety percent is non recharge water. In other embodiments, up to and/or over 4000 barrels per day of water may be removed.

Opposing bores 204 and/or 210 cooperate with each other to drain the intermediate area of the formation and thus reduce pressure of the formation. Typically, in each section of the formation between the bores 204 and/or 210, the section is drained by the nearest bore 204 and/or 210 resulting in a uniform drop in pressure between the bores. A pressure distribution 600 may be steadily reduced during production.

The main and lateral well bores 204 and 210 effectively increase well-bore radius with the large

surface area of the lateral bores 210 promoting high flow rates with minimized skin damage effects. In addition, the trough pressure production of the bores 204 and 210 affects an extended area of the formation. Thus, 5 essentially all the formation in the coverage area 202 is exposed to a drainage point and continuity of the flow unit is enhanced. As a result, trap zones of unrecovered gas are minimized.

Under virgin reservoir conditions for a 100 feet
10 deep coal bed, formation pressure may initially be 300
psi. Thus, at the time the pinnate pattern 200 is
formed, the pressure at the bores 204 and 210 and at
points equal distance between the bores 204 and 210 may
be at or close to the initial reservoir pressure.

15 During water and/or gas production, water is
continuously drained from the coverage area 202 to the
bores 204 and 210 and collected in the cavity 20 for
removal to the surface. Influx water 602 from
surrounding formations is captured at the tips of 604 of
20 the main and lateral bores 204 and 210 to prevent
recharge of the coverage area. Thus, the coverage area
is shielded from the surrounding formation with at or
over ninety percent of produced water being non recharge
water. Water pressure is steadily and substantially
25 uniformly reduced across the coverage area 202 until a
minimal differential is obtained. In one embodiment, for
a mature well, the differential may be less than or equal
to 20 to 50 psi. In a particular embodiment, the
pressure differential may be less than 10 psi.

30 As water pressure decreases in the coverage area 202, methane gas is diffused from the coal and produced through the cavity 20 to the surface 14. In accordance with one aspect of the present invention, removal of

approximately 500 barrels a day or other suitable large volume of water from a 200-250 acre area of the coal seam 15, in connection with the pinnate or other pattern 200 and/or a substantial uniform pressure drop in the 5 coverage area 202, initiates a kick off and early gas release. Removal volumes for kick off may be about one tenth of the original water volume, or in a range of one twelfth to one eighth, for one percent coal permeability, and may suitably vary based on suitable reservoir 10 conditions. Early gas release may begin within 1 to 2 months of pumping operations. Early gas release and kick off may coincide or be at separate times.

Upon early gas release, gas may be produced in two-phase flow with the water. The inclusion of gas in two-phase flow may lower the specific gravity and/or viscosity of the produced fluid thereby further dropping formation pressure in the area of two-phase flow and accelerating production from the formation. Moreover, the gas release may act as a propellant for two-phase 20 flow production. In addition, the pressure reduction may affect a large rock volume causing a coal or other formation matrix to shrink and further accelerate gas release. For the coal seam 15, the attendant increase in cleat width may increase formation permeability and may 25 thereby further expedite gas production from the formation. During gas release, kick off occurs when the rate of gas produced increases sharply and/or abruptly and gas production may then become self sustaining.

FIGURE 15 illustrates pressure drop in the coal seam 30 15 across line 15-15 of FIGURE 14 in accordance with one embodiment of the present invention. In this embodiment, the well is a mature well in a relatively shallow, 1000

feet deep coal seam 15. The lateral bores 210 are spaced approximately 800 feet apart.

Referring to FIGURE 15, distance across the coverage area 202 is shown on the X axis 652 with pressure on the Y axis 654. Pressure within the coverage area 202 is at or substantially near 3 psi at the lateral bores 210 and the main bore 204. Between the bores 204 and 210, the pressure differential is less than or equal to 7 psi. Thus, substantially all the formation in the coverage area is exposed to a drainage point and continuity of the flow unit is maintained. Trap zones of unrecovered gas are minimized. Pressure outside the coverage area may be at an initial reservoir pressure of 300 psi.

FIGURE 16 illustrates a structure 680 of coal in the seam 15 in accordance with one embodiment of the present invention. The coal may be bright banded coal with closely spaced cleats, dull banded coal with widely spaced cleats and/or other suitable types of coals.

Referring to FIGURE 16, the coal structure 680 includes bedding planes 682, face, or primary cleats 684, and butt, or secondary, cleats 686. The face and butt cleats 684 and 686 are perpendicular to the bedding plane 682 and to each other.

As water is removed from the coal structure 680 at an accelerated rate, the pressure reduction affects a large rock volume. The bulk coal matrix may shrink as it releases methane and causes an attended increase in the width of the face and/or butt cleats 684 and 686. The increase in cleat width increases permanentability which may further accelerates removal of water and gas from the coal seam 15.

FIGURE 17 is a flow diagram illustrates a method for surface production of gas from a subterranean zone in

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accordance with one embodiment of the present invention. In this embodiment, the subterranean zone is the coal seam 15. It will be understood that the subterranean zone may comprise gas bearing shales and other suitable formations.

Referring to FIGURE 17, the method begins after the region to be drained and the type of drainage patterns 50 for the region have been determined. Any suitable pinnate or other substantially uniform pattern providing less than 10 or even 5 percent trapped zones in the coverage area may be used to provide optimized coverage for the region.

At step 700, in an embodiment in which dual intersecting wells are used, the substantially vertical well 12 is drilled from the surface 14 through the coal seam 15. Slant and other single well configurations may instead be used. Next, at step 702, down hole logging equipment is utilized to exactly identify the location of the coal seam 15 in the substantially well bore 12. At step 704, the enlarged diameter cavity 20 is formed in the substantially vertical well bore 12 at the location of the coal seam 15. As previously discussed, the enlarged diameter cavity 20 may be formed by under reaming and other suitable techniques.

Next, at step 706, the articulated well bore 30 is drilled to intersect the enlarged diameter cavity 20. At step 708, the main well bore for the pinnate drainage pattern is drilled through the articulated well bore 30 into the coal seam 15. As previously described, lateral kick-off points, or bumps may be formed along the main bore during its formation to facilitate drilling of the lateral bores. After formation of the main well bore,

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lateral bores for the pinnate drainage pattern are drilled at step 710.

At step 712, the articulated well bore 30 is capped. Next, at step 714, the enlarged cavity 20 is cleaned in preparation for installation of downhole production equipment. The enlarged cavity 20 may be cleaned by pumping compressed air down the substantially vertical well bore 12 or other suitable techniques.

At step 716, production equipment is installed in the substantially vertical well bore 12. The production equipment may include a well head and a sucker rod pump extending down into the cavity 20 for removing water from the coal seam 15. The removal of water will drop the pressure in the coal seam 15 and allow methane gas to diffuse and be produced up the annulus of the substantially vertical well bore 12.

Proceeding to step 718, water that drains from the drainage pattern into the cavity 20 is pumped to the surface with the rod pumping unit. Water may be continuously or intermittently be pumped as needed to remove it from the cavity 20. In one embodiment, to accelerate gas production, water may be initially removed at a rate of 500 barrels a day or greater. At step 720, methane gas diffused from the coal seam 15 is continuously produced at the surface 14. Methane gas may be produced in two-phase flow with the water or otherwise produced with water and/or produced after the pressure has been suitably reduced. As previously described, the removal of large amounts of water from the coverage area of the pinnate pattern may initiate and/or kick off early gas release and allow the gas to be collected based on an accelerated production curve.

Next, at decisional step 724 it is determined whether the production of gas from the coal seam 15 is complete. In one embodiment, the production of gas may be complete after the cost of the collecting the gas 5 exceeds the revenue generated by the well. In another embodiment, gas may continue to be produced from the well until a remaining level of gas in the coal seam 15 is below required levels for mining operations. If 10 production of the gas is not complete, the No branch of decisional step 724 returns to steps 718 and 720 in which gas and/or water continue to be removed from the coal seam 15.

Upon completion of production, the Yes branch of decisional step 724 leads to the end of the process by 15 which gas production has been expedited from a coal seam. The expedited gas production provides an accelerated rate of return on coal bed methane and other suitable gas production projects. Particularly, the accelerated production of gas allows drilling and operating expenses 20 for gas production of a field to become self-sustaining within a year or other limited period of time as opposed to a typical three to five-year period. As a result, capital investment per field is reduced.

FIGURE 18 illustrates a gas production chart 800 for 25 an area of the coal seam 15 under virgin reservoir conditions in accordance with one embodiment of the present invention. In this embodiment, water and gas are drained to the cavity 20 through a uniform pinnate pattern and produced to the surface 14. It will be 30 understood that water and gas may be collected from the coal seam 15 in other suitable subsurface structures such as a well bore extending below the well bore pattern 50 so as to prevent pressure buildup and continue drainage

of the coverage area without departing from the scope of the present invention. In addition, it will be understood that drainage from the coverage area of the pinnate may continue without the use of a cavity, rat 5 hole or other structure. For example, the use of a volume control pump operable to prevent the buildup of a hydrostatic pressure head that would inhibit and/or shut down drainage from the coverage area may be used.

Referring to FIGURE 18, the chart 800 includes time 10 in months along the X axis 802 and gas production in thousand cubic feet (MCF) along the Y axis 804. A gas production curve 806 is based on production of 500 barrels per day of water. For this curve 806, gas production may kick off at approximately one month and 15 proceed at a self sustaining rate for an extended period of time. The rate may be self sustaining when water no longer need be removed to the surface by a pump. Gas production may peak before the end of the second month. Gas production may thereafter continue at a decline over 20 the next five to ten months until completed. On the decline, at least part of the production may be self sustaining. Thus, gas from the corresponding area of the coal seam 15 may be produced within one year. At kick off, pressure may be at 200 to 250 psi, down from an 25 initial 300 psi and thereafter drop sharply.

The gas production time may be further reduced by increasing water removal from the coal seam 15 and may be extended by reducing water production. In either case, kick off time is based on relative water removal and the 30 decline curves may have substantially the same area and profile. In one embodiment, the amount of water collected in the cavity 20 and thus that can be removed to the surface 20 may be controlled by the configuration of the

draining pattern 50 and spacing of the lateral bores. Thus, for a given coal seam 15 having a known permeability, water pressure and/or influx, lateral spacing may be determined to drain a desired volume of 5 water to the cavity 20 for production to the surface 14 and thus set the gas production curve 806. In general, lateral spacing may be increased with increasing permeability and may be decreased with increasing water pressure or influx. In a particular embodiment, drilling 10 expenses may be weighed against the rate of returns and an optimized pattern and/or lateral spacing determine. In this way, commercially viable fields for methane gas production are increased. A Coal Gas simulator by S.A. Holditch or other suitable simulator may be used for 15 determining desired lateral spacing.

Although the present invention has been described with several embodiments, various changes and modifications may be suggested to one skilled in the art. It is intended that the present invention encompass such 20 changes and modifications as fall within the scope of the appended claims and their equivalence.

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